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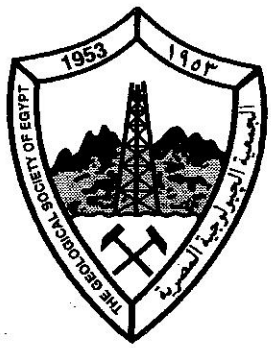

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STRATIGRAPHIC SETTING AND PALEOENVIRONMENT OF THE CONIACIAN - SANTONIAN IRONSTONES OF ASWAN, SOUTH EGYPT.

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Aswan ironstones are confined to the shallow marine succession of the Coniacian-Santonian Timsah Formation which was deposited during the ingression of the Tethys into central and southern Egypt. This formation is built up of four large-scale coarsening - upward sedimentary cycles, representing deposition under a repeated shallowing conditions accompanied with acceleration to current and wave activities during a gradual progradation of linear tidal sand/ooid bars on a basal shelf mud. Each cycle consists of smaller ones of medium- and small scales which represent delimited periods of fluctuation from quiet to agitated condition through the overall shoaling regime. The associated ironstones are classified according to their lithology, sedimentologic aspects and stratigraphic setting into: non-oolitic, oolitic and storm- generated reworked ironstones.

The non-oolitic ironstones are commonly observed within the basal mudstone units of the coarsening-upward cycles and includes: a) muddy banded and lenticular ironstones reflecting deposition from suspension, b) red and black sheeted sandy and silty ironstones which seem to be formed by the impact of current and waves during periods of sand influxes interrupting the mudstone deposition, and c) green laminated chamositic sandy ironstones deposited on the interbar areas (bar troughs) during short and intermittent periods of sea regression and transgression, dominated during the general progradation of the linear tidal sand/ooid bars.

The oolitic ironstones occur within the middle part of the coarsening-upward cycles and include poorly "lean" oolitic, true oolitic and oolitic sandy ironstones. These types reflect deposition in highly

agitated conditions along bar flanks and bar crests during regressive events terminating short-lived small-scale progradation regimes.

The reworked ironstones comprise channel-fill ironstone conglomerates formed within storm-surge channels dissecting the migrated sand/ooid bars and intraformational conglomerates. The latter were formed though syn-sedimentary erosion of subjacent ferruginous mudstone during an intermittent storm-dominated events.

INTRODUCTION

The present work is concerned with the Coniacian-Santonian ironstones of east Aswan, Upper Egypt (Fig. 1) and aims to elucidate their nature, composition, stratigraphic setting and mode of formation. The work is based on stratigraphic studies and detailed sedimentological analyses, Representative stratigraphic sections are measured and correlated and the sedimentological aspects and depositional environments of the recognized stratigraphic units are deciphered. The stratigraphic unit hosting the ironstone beds is examined in detail. The cyclic nature of this unit is emphasized and the subenvironments which prevailed during its formation are deduced. The associated ironstone beds are classified according to their lithological composition and sedimentological aspects. Non-oolitic ironstones including muddy, silty and sandy types, poorly "lean" to true oolitic ironstones and ironstone conglomerates are present. The stratigraphic settings of these types in accordance with the cyclicity of the hosting rocks and the environmental conditions prevailed during their formation are concluded .

The area east of Aswan (Fig. 1) represents the main occurrence of the Cretaceous oolitic ironstone bands of South Egypt which are confined to clastic successions belonging to the "Nubian" sandstones or "Nubia facies". South and west of Aswan, oolitic ironstone has been also recorded in El Umbarakap, Kalabsha, Affendunya temple, Kurusku, Wadi Halfa and Abu Simbel. Most of these occurrences are now flooded by Lake Nasser. Further south, Coniacian-Santonian oolitic ironstones are detected in the Abyad plateau of northern Sudan. New occurrences of oolitic ironstones are recently discovered along Wadi Garara and Gabal Abu Hashem, east of the well known occurrences of east Aswan (IEP, Iron Exploration Project, Phase II Report, 1995, Fig. 1).

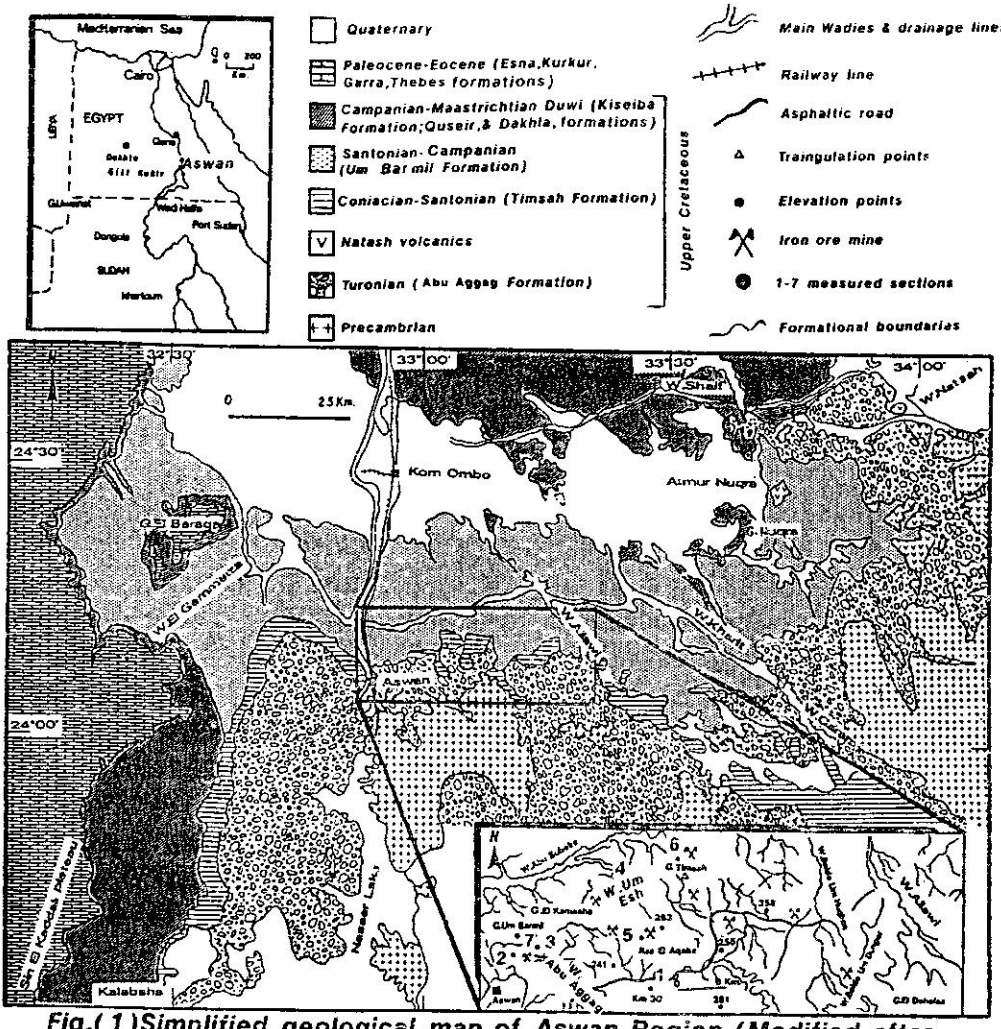


Fig.(1)Simplified geological map of Aswan Region (Modified after Klitzsch et al. 1987) and location of the measured sections

Two main theories have been previously postulated for the genesis an oolitic ironstones:

Sedimentary origin as suggested by Attia (1955), Faris and Abu Zeid (1961); and Bhattacharyya (1980, 1989). The iron ooids of Aswan ironstones are suggested to be formed in sedimentary basin from land- derived iron - rich constituents. However, Schwarz and Germann (1993 a,b) suggested that the iron ooids were formed during lateritization of the hinterlands and then transported into the marine basin, where deposition took place.

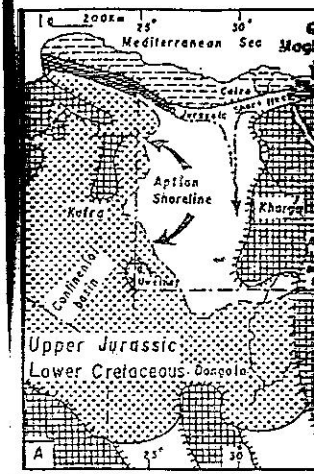
Volcanogenic origin is postulated by Tosson (1961), who proposed the derivation of iron from nearby volcanoes and its deposition in shallow marine environment.

Other studies on the genesis, mechanism of ooid formation, paleoenvironments and diagenesis of Aswan ironstones appear in the publications of Bhattacharyya (1980, 1983, 1989) and Germann *et al.* (1987).

LITHOSTRATIGAPHY & SEDIMENTOLOGY

East Aswan area is occupied by highly lateritized Precambrian norphic and igneous rocks of the Arabo-Nubian Shield, unconformably in by Upper Cretaceous clastic successions gently dipping to the (Fig. 1); including; from base to top: Abu Aggag Formation, Timsah ation and Um Barmil Formation. North of Aswan region, the rocks of formations are replaced by the typical "Nubian" type sandstones of the Formation. The Um Barmil Formation and the upper part of the Taref ation are followed by shallow marine phosphatic clastics of the anian-Maastrichtian Quseir and Duwi formations (= Kiseiba Formation itzsch and Lejal- Nicol (1984), as well as the Paleocene-Eocene Esna s, Kurkur, Garra and Thebes formations.

From the Cambrian to Late Cretaceous, east Aswan area represents ve land under erosion and the uplifted Precambrian rocks were cted to intensive lateritization processes (Fig. 2).



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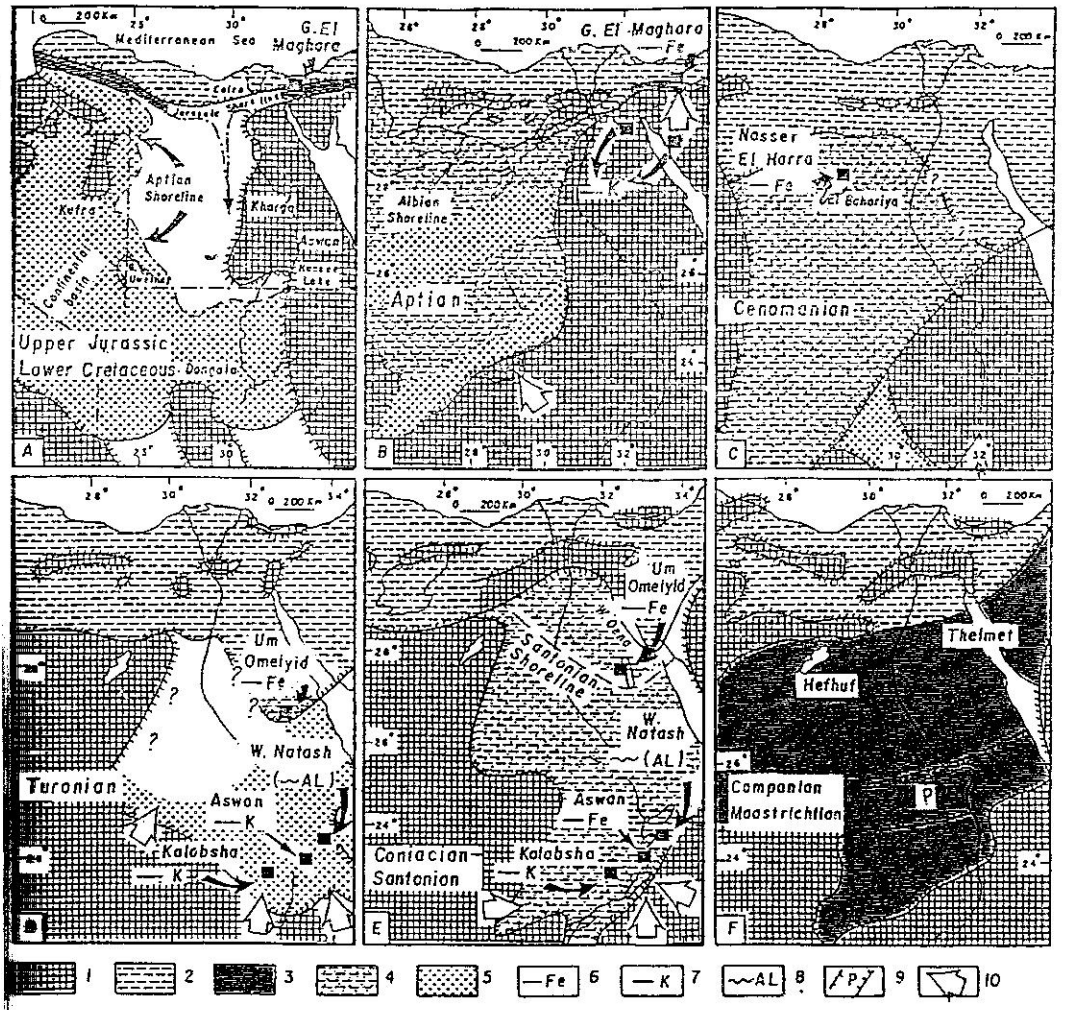
1-Positive areas;2-Open m
5-Fluviatial sediments;6-St
of economic phosphate d
Fig.(2)Paleogeography of
Figs.(2B-F)after Said 1990



1-Positive areas;2-Open marine sediments;3-Nearshore mixed environment;4-Fluviomarine sediments; 5-Fluviatial sediments;6-Stratiform ironstone;7-Koalin laterite;8-Bauxitic laterite;9-Limiting boundaries of economic phosphate deposits;10-Possible paleocurrent direction

Fig.(2)Paleogeography of the Mesozoic series and stages Fig.(2A)after Klitzsch and Wycisk 1987; Figs.(2B-F)after Said 1990a) and distribution of the related stratkm and stratabound deposits (Compiled by El Aref,1994)

1. The Turonian Abu Aggag Formation

During Turonian, major regressive phase has been established as a result of the Late Cretaceous - Early Tertiary tectonic phase (Meshref, 1990) accompanied with the elevation of southern Egypt including the study area together with numerous structures across northern Egypt, Sinai and Western Desert (Fig.2). Marine carbonates dominated over the structural lows of northern Egypt, while paralic sediments were deposited southward and crop out in the central part f Wadi Qena. Meanwhile, the extreme southern and western parts of Egypt represents positive areas (paleohighs) under erosion and received continental deposits, represented by Abu Aggag Formation of the study area and the equivalent lower part of the Taref Formation of the Western Desert.

The term Abu Aggag Formation was used by El Naggar (1970) to describe the whole sandstone and conglomerate succession just overlying the Precambrian basement rocks and underlying the lower oolitic iron ore horizon (horizon A) of Attia (1955). The present field observations reveal that this oolitic ironstone bed ("horizon") neither represents a diagnostic lithologic or sedimentologic changes from the underlying and overlying sediments, nor a persistent stratigraphic marker. This bed is encountered within the middle part of the proper shallow marine sequences of the Timsah Formation and often changes laterally into mudstones and ferruginous sandstones. Thus, it can not be used as a stratigraphic marker delineating the top of Abu Aggag Formation. The term Abu Aggag Formation is used here to cover the typical fluvial sediments overlying the weathered Precambrian rocks and underlying the genuine chamositic marine sediments of the Timsah Formation (Fig.3). These sediments are equivalent to facies 1 and the upper part of facies 2 of Van Houten & Bhattacharyya (1979) and facies 2 of Van Houten *et al.* (1984).

Abu Aggag Formation comprises a large-scale fining-upward cycle of braided stream system, being composed of three successive units: 1) a basal massive kaolinitic conglomerate unit representing channel lag deposits; 2) a middle trough and tabular cross-bedded conglomerate and conglomeratic sandstone unit representing accumulation in distal channels of braided streams, and 3) an upper mudstone-dominated unit representing flood plain sedimentation. In W. Natash and W. Garara, NE and E of the study area, the upper part of Abu Agag Formation interfingers with and is

intruded and capped by, Natash volcanic dykes, sills and flows followed by the Timsah and/or Um Barmil formations.

The Abu Agag Formation seems to be barren of any fossils but may include some poorly preserved plant remains and root molds. According to Hermina (1989), Abu Aggag Formation is of Turonian age and is equivalent to the lower part of the Turonian-Santonian Taref Formation of the Western Desert. Leaf remains (*Aralie aff, obtusilobun, Ficophyllam* Sp.), indicating an age not older than Aptian-Albian, have been recorded by Germann et al. (1987). Natash volcanics, interfingering and terminating Abu Aggag Formation, are dated 84 to 100 m.y. (Ressetar and Nairn, 1980; and Hashad et al., 1982) which indicate a Turonian age. Issawi and Jux (1982) and Seliem and Said (1992), however, give a Paleozoic age to their Wadi Malik Formation (= Abu Aggag Formation). This age is based upon the occurrence, according to these authors, of the Paleozoic ichnofossil *Bifungites* in the Timsah Formation, above the lower iron ore horizon A of Attia (1955). Since genuine Late Cretaceous (Coniacian-Santonian) marine fossils are described from the lower horizon than that yielding the doubtful *Bifungites*, the proposed Paleozoic age of Abu Aggag Formation becomes uncertain.

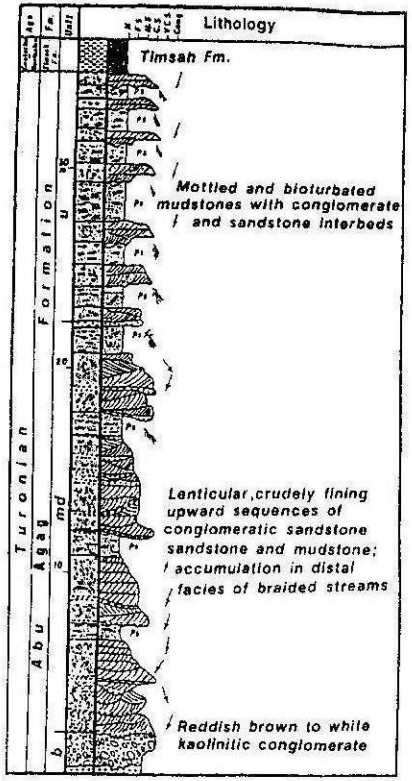
2. The Coniacian - Santonian Timsah Formation

Southward transgression prevailed during the Coniacian - Santonian time. This transgressive phase brought the Tethyan Sea inland as far south as Gabal Abyad Plateau in Sudan (Fig. 2). The transgressing sea remained more or less in a small southwestward embayment (Fig. 2E) bordered to the west by the Kharga uplift and to the southeast by Precambrian hills. Genuine marine conditions prevailed in the northern part of Egypt, and led to the deposition of the Coniacian-Santonian glauconitic shales and fossiliferous carbonates of the Matulla Formation. Southwards, an increasing shallowing is indicated by the deposition of the paralic Hawashiya Formation (Kallenbach and Hendriks, 1986) in Wadi Qena and the Timsah Formation further south in Aswan region.

The Timsah Formation is formed of marine clastic successions of coarsening - upward tendency (Fig. 3), overlying the Turonian Abu Agag Formation and disconformably underlying the fluvial Um Barmil Formation (Santonian - Campanian). According to El Naggar (1970), the Timsah Formation represents the oolitic iron ore bearing Middle Group of Attia

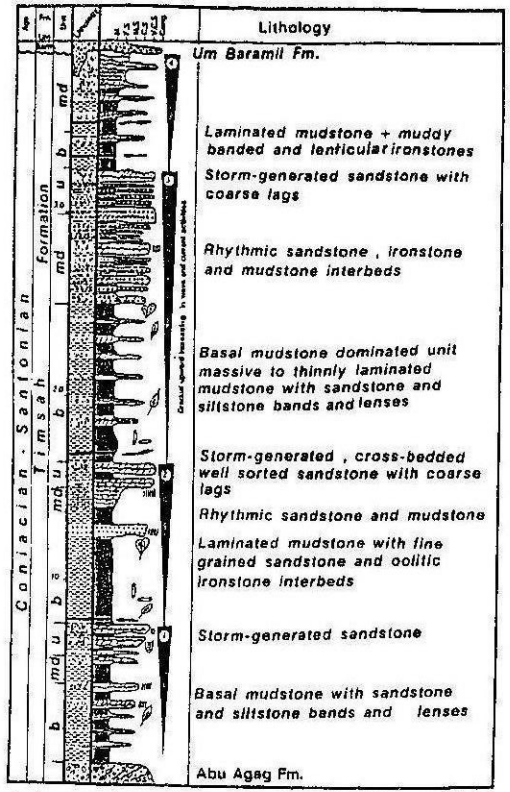
Fig. 3 Type sections of the Abu Aggag, Timsah and Um Barmil formations (Locations in figure 1).

1= paleosol ; 2= Lag deposits, 3= conglomerate ; 4= pebbly sandstone ; 5= sandstone ; 6= siltstone ; 7= mudstone ; 8= Muddy banded and lenticular ironstone ; 9= Red black sheeted sandy and silty ironstone ; 10= Green laminated chamositic ironstone ; 11 = Poorly "lean" oolitic ironstone ; 12= True oolitic ironstone ; 13= oolitic sandy ironstone ; 14= Reworked ironstone conglomerate ; 15= Roots ; 16= plant remains (leafs) ; 17= Horizontal and vertical burrows ; 18= Desiccation ; 19= scour and fill structure ; 20= Trough cross lamination ; 21= Tabular cross-lamination ; 22= Ripple cross-lamination ; 23= Horizontal lamination; 24= fining- upward ; 25= coarsening-upward ; 26= iron pisoid ; 27= iron ooid ; 28= *Inoceramus* sp., 29= Boudinage structure ; 30= *Diplocraterion* ; 31= *Skolithos* ; 32= Direction of current ; 33= Erosional contact.



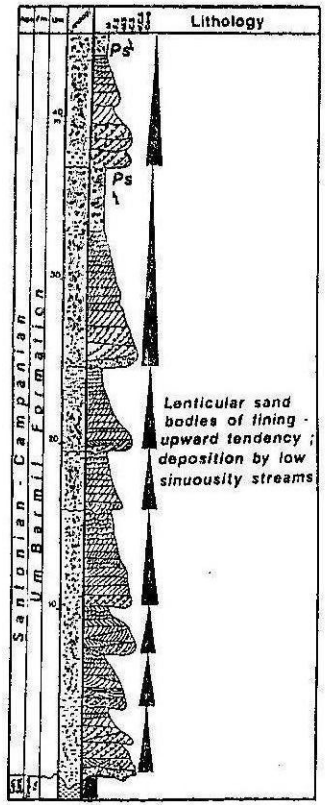
b=Basal unit ; md=Middle unit ; u=Upper unit

A)Abu Agag Formation (Turonian),KM 30 (Sec.1)



b=Basal mudstone dominated unit ; md=Middle sandstone and/or ironstone rhythmic unit ;u=Upper storm-generated unit

B)Timsah Formation (Coniacian-Santonian), Gabal Timsah (Sec.6)



C)Um Barmil Formation(Sntonian-Campanian) Gabal Timsah(Sec.6)

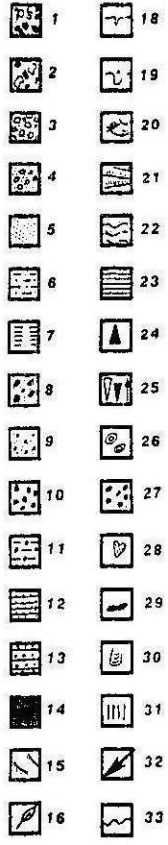


Fig.(3)Type sections of Abu Aggag , Timsah and Um Barmil formations. (Location in Fig.1)

(1955) which is defined at the base by the first appearance of the lowest iro ore horizon A of Attia (op.cit.) and at top by a conglomeratic bed jus overlying the uppermost iron ore horizon B of Attia. This ironstone bearin unit is currently classified into three coarsening-upward sequences includin marine fossils with total thicknesses varying between 10 and 40 meter (Bhattacharyya, 1980). The lowermost sequence starts at the base by laminated greenish-grey claystone containing plant remains, while the uppermost third sequence is terminated by intensely burrowed muddy ferruginous fine-grained sandstone or chamositic-hematitic oolitic ironstone.

Ichnofossils like *Thalassinoides, Skolithos, Rhizocorallium, Teichichimus* and *Diplocraterion* are recorded in the bioturbated sandstones of this formation (Cox, 1956). Based on the marine fossils *Inoceramus (Platyceramus) Cyloides, Inoceramus (valviceramus) balli* and other lamellibranchiates like *Iscoardia agyptica* and *Unio* sp. (Klitzsch, 1984 and Klitzsch and Wycisk, 1987), this formation is assigned to Coniacian-Santonian. Palynological investigations of Sultan (1985) support this age Timsah Formation contains abundant plant remains. This following Upper Cretaceous angiosperm leaves and fruits have been reported by Lejal-Nicol (1987) and Germannn *et al.* (1987): *Celastrophyllum Latifolium Ficophyllum* sp.; *Mangoliaepghllum bahariyensce*; *Nelumbites Schweinfurthi*; Paulliniacarpon; *Rogersia aegiptica*; *Tilaephyllum* sp. and *Ulmocarpon* sp. The fossil content of the Timsah Formation and its stratigraphic setting and the absence of any traces of Paleozoic fossils argue against the Carboniferous age proposed by Issawi and Jux (1982) and Seliem and Said (1992).

In the present work, the Timsah Formation is extended to include the whole genuine marine successions that encompassed between the fluvial Abu Aggag and Um Barmil formations (Fig. 3). The measured section in the type locality Gabal Timsah, attains about 40 m thick and consists of four large-scale coarsening-upward cycles (6-16 m) containing ironstone bands, lenses and laminae of different lithological and textural types. The second and third large-scale coarsening - upward cycles may be correlatable with the A, B and C cycles of Bhattacharyya (1980). The fourth cycle is generally free of oolitic ironstone bands and displays an upward continuation of the coarsening - upward regime. It is terminated by bioturbated storm-generated sandstone bed, up to 2 m thick. This bed is traced everywhere in the study area and can be considered as a good persistent stratigraphic marker separating the marine Timsah Formation from the overlying fluvial fining

upward sequences of Um Barmil Formation (Fig. 3). In some places, the fourth coarsening - upward cycle is channeled by the lowermost coarse - grained to conglomeratic sandstones of Um Barmil Formation.

The lithology and sedimentary features of the observed coarsening-upward cycles (Table 1) reflect deposition under repeated upward increase in the current and wave activities that prevailed during gradual progradation of linear tidal sand/ooid bars on basal shelf muds.

Each large scale coarsening - upward cycle is formed of smaller cycles of medium and small scales (Table 1) and is characterzied by a sharp contact against the underlying one. It starts with mudstone - dominated unit, up to 8 thick, being formed of laminated green mudstone with or without lenticular layers of rippled sandstones and dark brown, red to black ferruginous (chamositic) mudstones. Plant remains are commonly distributed within this unit. Marine pelecypods: *Inoceramus* and *Isocardia* are well preserved in the basal mudstones of the second and third cycles. Such basal mudstones represent deposition in low energy environment within inter-bar areas (troughs) of migrated ooid / sand bars.

The basal mudstone-dominated unit is followed by rhythmically alternating and laterally intertonguing beds of kaolinitic and ferruginated sandstones, oolitic ironstone and mudstone, (2-6m) comprising the middle unit of the coarsening-upward cycle. The sandstones and oolitic ironstones are often cross-laminated to cross-bedded and highly bioturbated by *Skolithos* and *Diplocraterion*. The lithologic associations and sedimentological characteristics of this middle unit suggest deposition along lower and upper flanks of the migrated sand/ooid bars.

The upper unit of the coarsening - upward cycle is formed of 2 to 4m of sheeted sandstones and/or oolitic ironstone with ironstone conglomerates. Hummocky cross stratification and bioturbation are the main sedimentary features observed in this unit V. The sediments of this unit represent deposition in highly agitated (storm-dominated) environment that prevailed along the upper flanks and crests of the migrated sand/ooid bars.

3. The Santonian-Campanian Um Barmil Formation

Sea retreat existed during the Santonian-Campanian time. Consequently fluvial clastics of Um Barmil Formation accumulated in the

Table 1 : General characteristics of the large, medium and small scale coarsening-upward cycles of the Tinsah Formation

Cycle	Thickness	Basal unit	Middle unit	Upper unit
Large scale cycle	6 - 18 m	Thinly Laminated green mudstone ± ferruginous (chamositic) mudstone lenses. Abundant boudinage and sausage structures, ripple cross lamination, plant remains and marine pelecypods.	Cyclic alternated and laterally inter-tongued laminated mudstone and ripple cross laminated to cross bedded ferruginous sandstone and/or oolitic ironstone. Coarsening -upward arrangement and common penetration by *Skolithos*.	Storm-generated sheeted sandstone ± ironstone conglomerates showing hummocky cross stratification, ripple laminations, & burrowing by *Skolithos*, *Diplocraterio* n & *Monocraterion*.
Medium scale cycle	2 - 5 m	Thinly laminated & burrowed mudstone with common plant remains.	Rhythmic intercalations of rippled ferruginous sandstone and oolitic ironstone ; abundant penetration by *Skolithos*.	Cross-bedded to cross-laminated sandstone or oolitic ironstone.
Small-scale cycle	40-150 cm	Laminated mudstone.	Mottled and bioturbated ripple cross-laminated siltstone and sandstone.	Oolitic ironstone and/or ferruginous oolitic sandstone.

study area and shelf marine sediments dominated to the north. This formation is formed of a series of brown lensoidal sand bodies of fining-upward tendency, just overlying the uppermost coarsening-upward cycle (cycle 4) of the Timsah Formation with a characteristic scouring contact (Fig. 3). Each fining-upward sequence starts in the base by channel lags followed by moderate to high angle trough and tabular cross-bedded medium-to coarse-grained sandstones and conglomerates. The tabular cross bed sets are, 0.5 to 2m think. Some cross sets are separated by very thin flat-lying parallel laminated sandstones and conglomerate. The cross-bedded sandstones and conglomerates grade upward into current ripple laminated fine-grained sandstone and siltstone, up to 160 cm thick, with intercalations of very low angle trough to laterally extended tabular cross-bedded sets, up to 10 cm thick. Relatively thick mottled and rooted paleosol intervals terminate the uppermost fining-upward sequences. The internal fining - upward pattern and sedimentary structures of these sand bodies suggest deposition from low sinuousity braided stream (Saller and Dickinson, 1982).

PROGRADATIONAL SEQUENCES AND RELATED IRONSTONE TYPES

Based on the lithology, sedimentological aspects and composition of the Timsah ironstone beds, they are classified into three main groups which are further subdivided into 9 types (Table 2). The stratigraphic settings of these types reveal their general upward arrangement and their intimate association with certain levels within the large-scale coarsening - upward progradational sequences (Figs 4 & 5).

1. Non-oolitic ironstones

This group of ironstones comprises the ferruginous mudstones and sandstones, with > 15%Fe, which are often recorded within the basal greenish white kaolinitic mudstone units of the large-scale coarsening-upward cycles (type 1-4 Table 2). Type 4 of this group is commonly observed in the basal part of the middle rhythmic units of these large-scale coarsening-upward cycles. These ironstone types are of less important economic values, but they are of prime importance in the understanding of the genesis and mode of formation of the overlying oolitic ironstone types.

Table 2 : Classification of Aswan ironstones

	Group	Ironstone Type	Average Fe_2O_3 content %	Depositional environment
C	Reworked storm generated ironstone conglomerates	9. Intra-formational ironstone conglomerate	34.7	Distal storm layers
		8. Channel-fill ironstone conglomerate	36.73-41.48	Channel-fill sequence on bar crests
B	Oolitic ironstones	7. Oolitic sandy ironstone	25.71	Bar crests
		6. True Oolitic ironstone	(68.18-76.52)	Upper and lower bar flanks
		5. Poorly "lean" Oolitic ironstone	58.28	
A	Non-Oolitic ironstones	4. Green, laminated chamositic sandy ironstones (chamositic sandstone)	(37.36-53.8)	Lower bar flanks and bar troughs
		3. Black sheeted sandy and silty ironstones (black ferruginous sandstones and siltstones	26.5	Distal storm layers
		2. Red sheeted sandy and silty ironstones (red ferruginous sandstones and siltstones)		
		1. Muddy banded and lenticular ironstones.	74.72-74.03	Low energy shelf muds

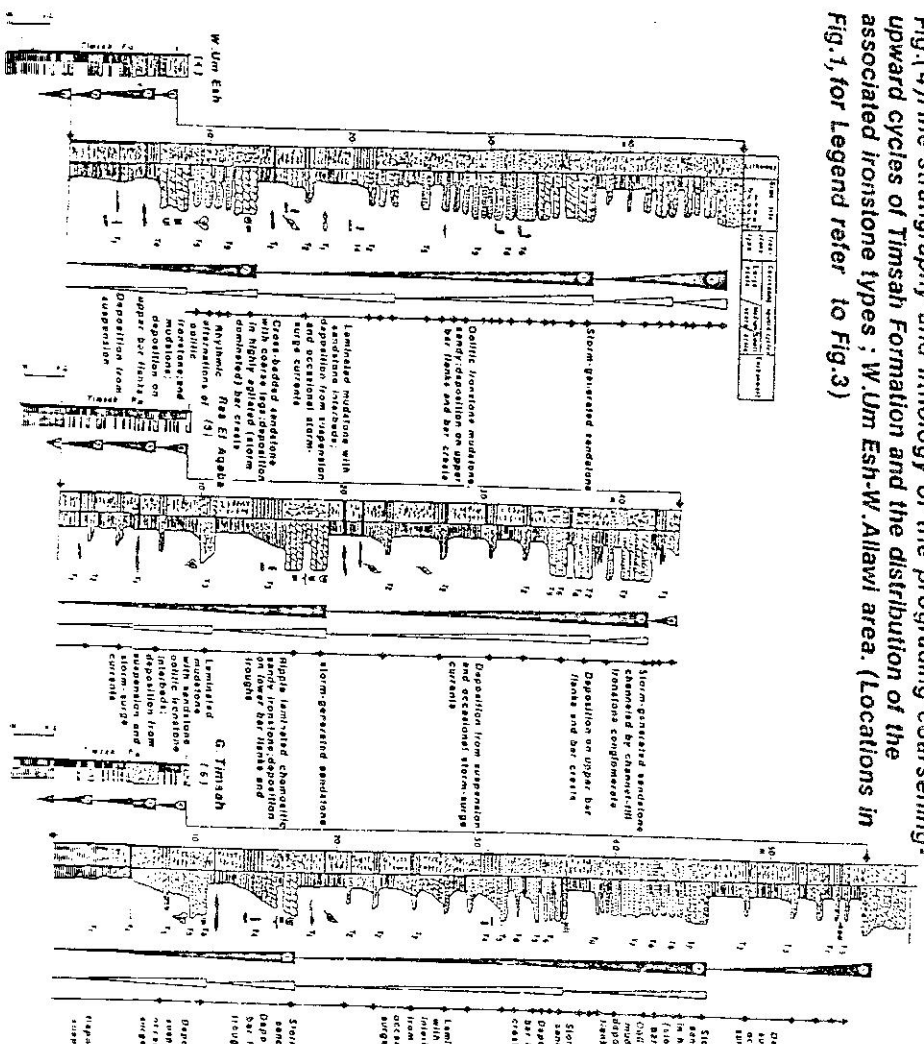


Fig.(4)Fine stratigraphy and lithology of the prograding coarsening-upward cycles of Timsah Formation and the distribution of the associated ironstone types ; W.Um Esh-W.Allawi area. (Locations in Fig.1, for Legend refer to Fig.3)

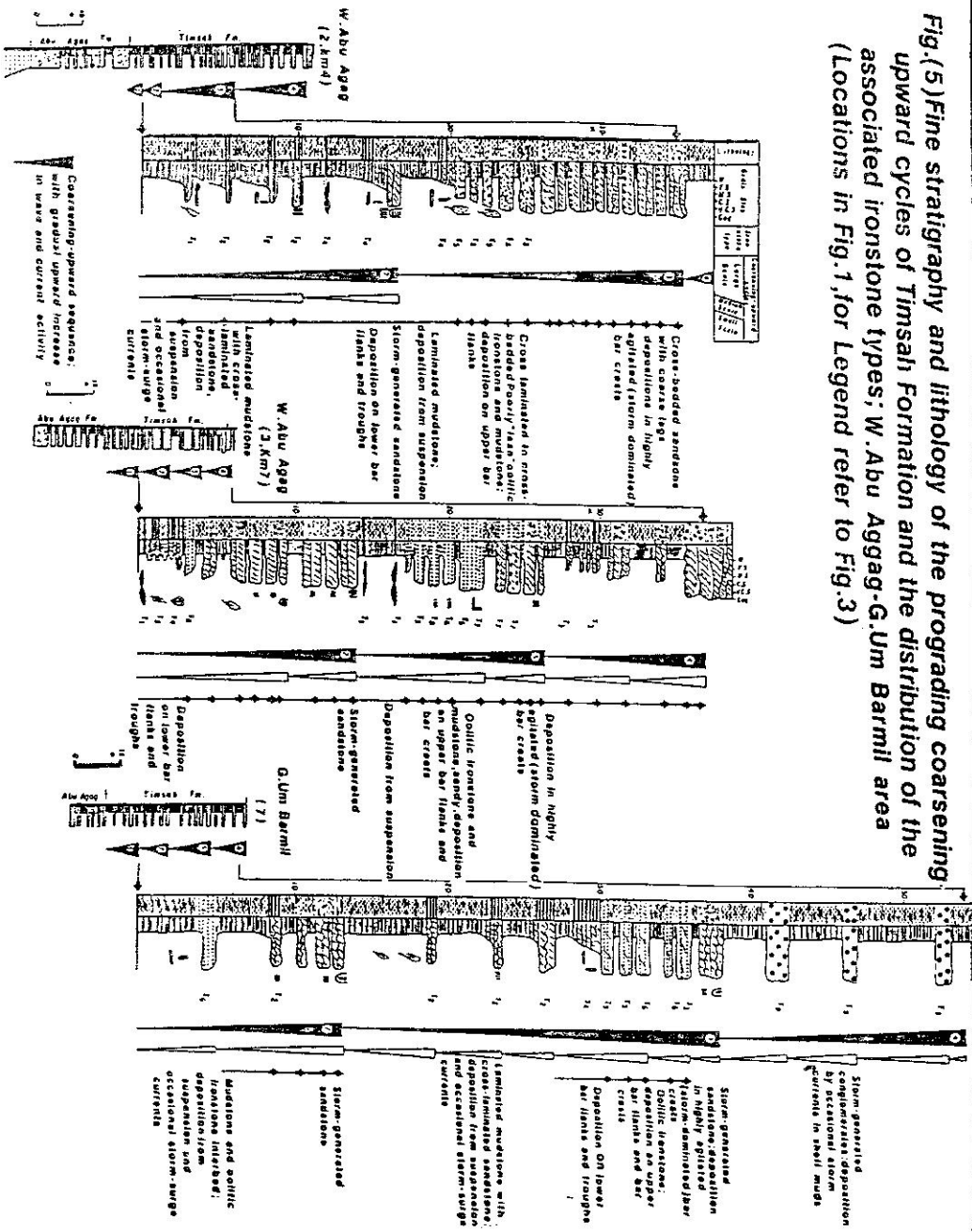


Fig.(5)Fine stratigraphy and lithology of the prograding coarsening-upward cycles of Timsah Formation and the distribution of the associated ironstone types; W.Abu Aggag-G.Um Barmil area (Locations in Fig.1,for Legend refer to Fig.3)

The ferruginous - mudstones (muddy ironstone) form stratiform black to deep brown lenses and bands of different thicknesses. They consist mainly of ultra - fine - grained kaolinite intermixed with dusty hematite and amorphous iron oxyhydroxide. The ironstone lenses exhibit a characteristic boudinage structure with convex up and convex down surfaces and flattened and tapered ends. Less frequent lenses of convex down surfaces and nearly flat upper surface are also present. Ferruginous laminae either end against the ironstone lenses, (whereas later laminae rise steeply toward it) or pass over it in a gentle arch. The laminae in the surrounding kaolinitic mudstone are less disrupted and flat in the upper surfaces, while they are highly compacted along the lower convex side of the ironstone lenses. The ferruginous mudstone bands, (up to 20 cm thick and 10 m long) are commonly observed in a higher stratigraphic level within the mudstones of the large-scale coarsening - upward cycles. These bands are usually of flattened and tapered ends and they are also thinnly laminated, and highly disrupted by vertical and horizontal burrows (Figs. 4 & 5).

The red and black sheeted sandy and silty ironstones (ferruginous siltstones and sandstones) are commonly present as thin sheeted red and black beds and lenses usually associated or just overlying the aforementioned muddy ironstones within the basal mudstone units of the second and third large - scale coarsening - upward cycles (Figs. 4 & 5). The ferruginous sandstone beds range in thickness from 30 to 60 cm and extend from 200 m to 2.5 km, while the lenses range from 4 to 30 m in length and from 20 to 40 cm in diameter. These beds and lenses are horizontally laminated in their basal parts and ripple cross-laminated along their upper parts. They commonly change laterally and vertically into kaolinitic and chamositic-kaolinitic sandstones and siltstones and may include thin lenticular bodies and small pockets of yellow massive mudston. They are dominated by vertical ferruginated burrows which, in some places, led to complete obliteration of the primary sedimentary structures.

The green laminated chamositic sandy ironstones is widespread in the basal part of the middle rhythmic units of the large-scale coarsening-upward cycles. Lithologically, it consists of rhythmic alternating thin bands and laminae of soft green mudstone and hard protruded fine - grained sandstone and/or siltstone showing small scale coarsening - upward tendency (Fig. 4 & 5). In some instances these lithologies change laterally and vertically into oolitic ironstones and/or white kaolinitic cross-laminated to cross-bedded sandstones.

Depositional environment

1. The thin lamination character of the basal mudstones enclosing the muddy ironstones reflects deposition during shallow marine transgression and low clastic input. During these periods mud was deposited from suspension and thin beds of sand were spread by storm-surge currents giving rise to ripple-cross laminated fine-grained sandstone and siltstone bands and lenses. The associated muddy ironstones represent an original iron-rich muddy sediments modified by diagenesis. Iron seems to be redistributed and concentrated in certain domains, where the requisite pore-water chemical conditions are obtained soon after deposition. The development of the observed boudinage structure depends on the difference in competency between the original iron-rich muddy sediments and the enclosing unferruginated sediments.

2. The ferruginous sheeted sandstone and siltstone bands and lenses represent coarse-grained lithologies within the enclosing basal mudstones. They seem to be formed by the impact of currents and waves during periods of sand influxes interrupting the mudstone deposition. Water movement over a sand bed as unidirectional current, oscillatory waves or a combination of both may give rise to ripples. The formation of ripples is related to deposition in a very shallow water (1-3 cm deep). Hobday and Morton (1980) related the formation of similar ripple laminated sandstones to the action of storm-surge currents which spread the detrital sands laterally forming sandstone bands and lenses. The abundance of *Skolithos* in these sheeted sandstone bands and lenses indicates deposition in the shale - lowest, wave - agitated upper shoreface and foreshore (Rhoads, 1975). The yellow mudstone lenses represent fine sediments deposited in the troughs of the subaqueous current ripples. They are suggested to be formed by the continuous transportation of the mud from the ripple crests and their deposition in depressions (ripple troughs). The deposited mud was covered and compressed by the incoming sands.

The sheeted sandstone bands and lenses and the host mudstones are equivalent to the shelf prodelta grey to black laminated shale and the associated sandstone lenses and thin shell beds of Devonian Bokkeveled Basin of South Africa (Tankard and Barwis, 1982). They also compare well

with the basal parts (shelf muds) of the typical coarsening - upward sequences of the Oxfordian sand bar deposits, Western Interior, USA (Brenner and Davies, 1973), the Cretaceous Sussex sandstones, Wyoming, USA (Berg, 1975).

3. The green laminated chamositic sandy ironstones represent deposition during short and intermittent periods of sea regressions and transgressions within the frame of the general seaward progradation of linear tidal sand/ooid bars. The green chamositic mudstone beds reflect deposition during short-lived transgressive periods, while the sandstone bands and laminae reflect deposition during sea regressions accompanying progressive progradation (migration) of the linear tidal sand bars. The presence of green chamositic clay laminae within the mudstone bands indicates their deposition in a shallow marine, but restricted, environment. The dark green colourations of the mudstones suggest deposition in a reducing water-logged conditions (Selley, 1982), while the red colouration of the sandstones and their ripple-cross laminations support their deposition during more agitated periods by oscillatory and combined flow currents (Selley, op.cit). The predominance of *Skolithos* within the sandstone bands and laminae support their deposition in the shale-lowest, wave - agitated upper shoreface and foreshore. Lithologically, this ironstone type is identical to unit No. 4 of Berg (1975) of the coarsening - upword sequence of the Upper Cretaceous Sussex sandstones, Wyoming, USA, which is related to deposition by current ripples in response to tidal current on lower bar flanks and troughs. This type of ironstone is also correlatable with the basal and middle parts of the small - scale coarsening - upward cycles described by Cotter and Link (1993).

2. Oolitic ironstones

The oolitic ironstones are subdivided into three types (Table 2) poorly "lean" oolitic ironstones (type 5); true oolitic ironstone (type 6) and oolitic sandy ironstone (type 7); depending upon the proportion of the skeletal components relative to the enclosing clayey matrix and the proportion of the different skeletal components relative to each others.

The stratigraphic settings of these ironstone types indicate their intimate genetic relation with the short and long-lived progradation cycles of

the Timsah Formation (Fig. 4 & 5). Each of these types has a certain stratigraphic position within these cycles. The true oolitic ironstones are often associated with, and laterally changed into, oolitic sandy ironstones and sandstone (Figs. 4-6).

Poorly "lean" oolitic ironstone

The poorly "lean" oolitic ironstones (Bhattacharrya, 1989) form transitional beds occurring between the basal mudstones and the uppermost true oolitic ironstones and /or oolitic sandy ironstones of the small - scale coarsening - upward cycles (Fig. 4 & 5). In some instances poorly "lean" oolitic ironstone beds are rhythmically alternated with green mudstones along stratigraphic levels just underlying the true oolitic ironstone beds of the middle rhythmic units of some large - scale coarsening upward cycles. The poorly "lean" oolitic ironstone beds are generally mottled, highly bioturbated and change laterally into thinnly laminated and burrowed green mudstones. Internally, they are muddy and consist of reddish green chamositic clays containing horizontally arranged and widely spaced green chamositic ooids, peloids and sand - sized quartz grains. Ripple - cross - laminations are common. .The coarse ooids are commonly concentrated along the ripple crests while smaller ooids are concentrated along the ripple troughs.

True oolitic ironstones

The true oolitic ironstone type consists entirely of closely spaced (grain - supported) ferruginous ooids (>95%) with less abundant detrital quartz grains, kaolinitic rock fragments and ferruginous clayey materials (<5%). These components form fairly stratified red beds of about 80 cm thick, often confined within the middle and upper units of the second and third large - scale coarsening - upward cycles (Fig. 4 & 5). Individual beds of this type overlying green mudstone and/or poorly "lean" oolitic ironstone bands comprise sequences of small - scale coarsening - upward regimes, best observed in W. Um Esh, Ras El Aqaba and G. Timsah areas (Fig. 4 & 6). Kaolinitic mudstone fragments are frequently distributed along the contact between the red oolitic beds and the underlying poorly "lean" ironstones or mudstones.

The oolitic ironstones beds may extend laterally for about 10 km and often change, through oolitic sandy ironstone, into sheeted sandstones or

mudstones (Fig. 6). They are highly bioturbated and penetrated by *Skolithos* and *Diplocaterion*; however, flaser bedding, symmetrical wave ripples and graded bedding can be observed in some undisturbed sites. Burrowing may also penetrate the underlying mudstones or poorly "lean" oolitic ironstones, where mud-lined burrows predominate.

The thickness variations of the oolitic ironstone beds and their lateral changes reflect an inverse relation between the detrital influxes and formation of oolitic ironstone. There is a remarkable increase in the thickness of the oolitic ironstone beds with the decrease in the thickness of the overlying sheeted sandstones and decrease in the thickness of the underlying mudstones and poorly "lean" oolitic ironstone beds (Figs. 4 & 5).

Mineralogically, the ooids of the oolitic ironstones are of chamositic, chamositic - kaolinitic, kaolinitic, kaolinitic - hematitic and hematitic composition. The mode of occurrence of these mineralogical varieties within the prograding cycles reveales the predominance of the chamositic ooids within the middle parts of these cycles and the predominance of the hematitic and kaolinitic ooids toward the upper part. According to Mesaed (1995) and EL Araf etal (1996), the microfabric evolution of these ooids support their formation either by: a) intra sedimentary accretions below the sediment surface ; b) mechanical (extra - sedimentary) accretion along the sediment-water interface or c) intra - and extra - sedimentary accretions.

The original microfabric and mineralogical composition of the mechanically accreted ooids are partially to completely obscured by the impact of post - depositional diagenetic processes involving authigenic growths of kaolinite and hematite, compaction and development of shrinkage cracks during periods of dewatering and dehydration, (EL Aref etal 1996).

Oolitic sandy ironstone

Oolitic sandy ironstone beds, consisting of grain-supported quartz grains and less abundant ferruginous ooids, represent the lateral facies equivalent of the true oolitic ironstones which together terminate the small-scale coarsening-upward cycles of the second and the third large-scale coarsening - upward cycles (Fig. 4-6). Some of these cycles are terminated by oolitic ironstones together with oolitic sandy ironstone interbeds. In some other places, the true oolitic ironstones are completely replaced by oolitic

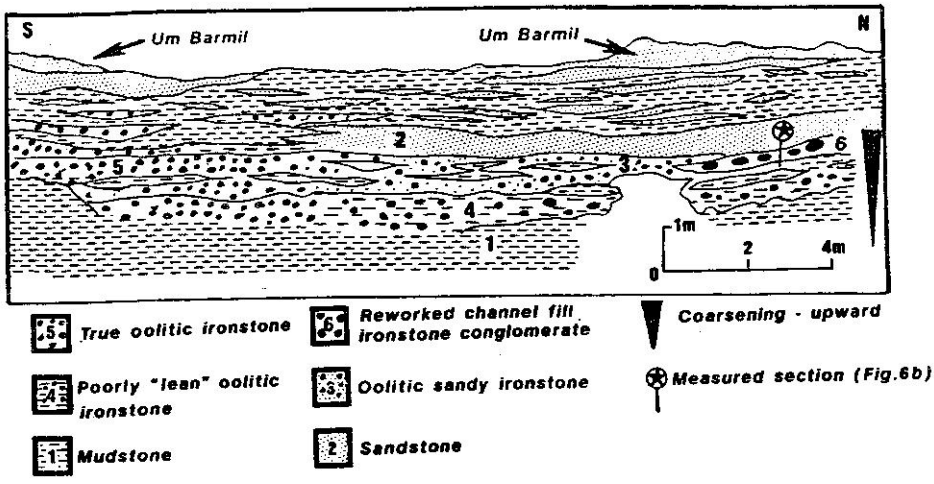


Fig.(6a)Explanatory field sketch showing the distribution of the different oolitic ironstone types within the coarsening-upward (shoaling) cycles,Ras El Aqaba area.

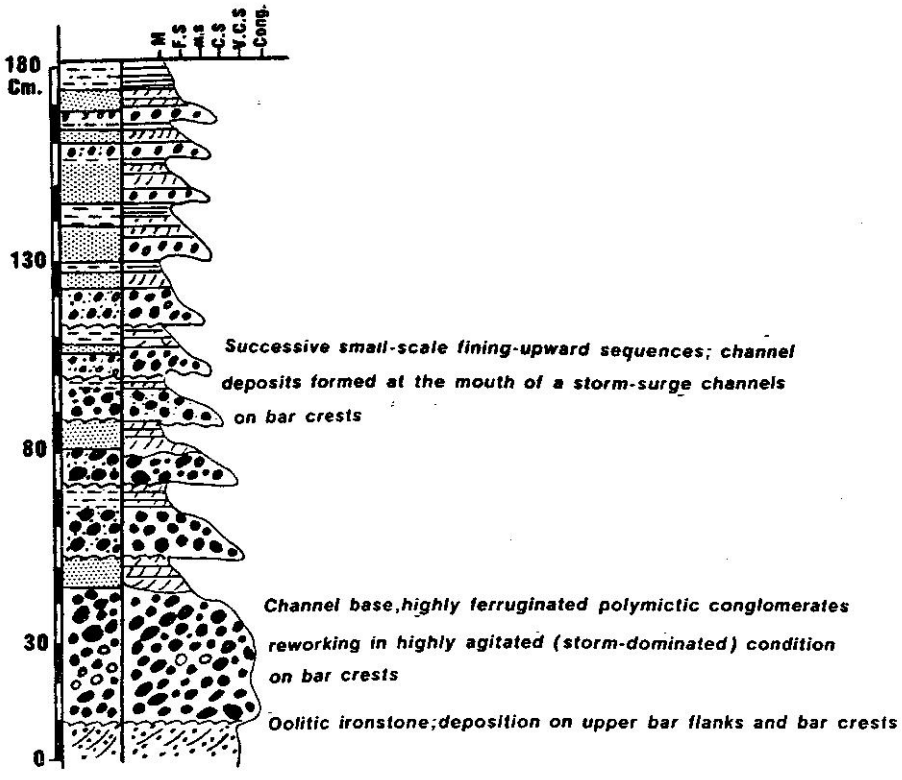


Fig.(6b)Detailed stratigraphy of channel-fill ironstone conglomerates (ironstone type 8) Ras El Aqaba area.

sandy ironstones or sheeted cross-laminated to cross-bedded sandstones. They exhibit horizontal and cross-laminations, flaser bedding and bioturbation structures. Kaolinitic mudstone fragments delineate the lower contacts of the oolitic sandy ironstone beds.

Depositional environment

1. The stratigraphic positions of the described oolitic ironstone types reflect their intimate genetic relation with the short-lived transgressive- regressive events which are expressed by the small and medium scale coarsening - upward cycles developed during the long-lived progradation or coarsening-upward regimes. Ferriferous ooid accumulation after the waning of coarsening - upward cycles have been also documented by several authors (e.g. Wright, 1977; Kimberley, 1979 and James and Van Houten, 1979, among others).

2. The lithological characteristics and sedimentary structures of the poorly "lean" oolitic ironstones and the underlying, and equivalent, green laminated sandstones and mudstones suggest deposition during the transgressive periods in a relatively calm condition along lower bar flanks or within areas (bar troughs), affected by an intermittent current activities.

3. The oolitic ironstones are commonly described as condensed deposits that accumulated during a transitional stage which developed either at the end of a regional regression (Sellwood and Jenkyns, 1975) or the beginning of renewed transgression (Kimberley, 1979), while thicker correlative marine sediments were deposited elesewhere. The stratigraphic setting of Aswan oolitic ironstones, their composition, textural maturity, internal sedimentary structures and lateral facies changes strongly emphasize the concentration of the ferruginous ooids in highly agitated conditions along bar flanks and bar crests during the regressive events which terminate the short-lived (small-scale) progradational regimes. Mechanical accretion of chamositic - kaolinitic and/or ferruginous muds and oolitization appear to have taken place on the bar flanks and crests during the high stand periods. During the regressive events, winnowing, transportation and redeposition of the formed ooids took place and the coarse sediments including quartz grains and/or iron ooids prograded gradually on the interbar shelf muds.

This is indicated by the graded bedding, rippling and burrowing of the oolitic ironstone beds. A similar bar (shoal) progradation model is recently suggested by Cotter and Link (1993) for the Clinton oolitic ironstones of pennsylvania. Association of ooid development with reduced influx of detritus is clearly expressed by the rarity of detrital grains in the true oolitic ironstone beds and the lateral replacement of these beds by oolitic sandy ironstones or sandstones in areas receiving much influx of detritus.

3. Reworked storm-generated ironstone conglomerates

Two types of storm-generated ironstone conglomerates of different stratigraphic setting and depositional processes are recognized, these are:
1) Channel-fill ironstone conglomerate (type 8 ironstone),and
2) intra-formational ironstone conglomerate (type 9 ironstone).

Channel -fill ironstone conglomerate

This type forms a unique, horizontally arranged channel-like lenticular conglomerate mass embedded within the storm-generated sandstones and oolitic ironstones, culminating the third large-scale coarsening-upward cycle. It is about 100 m long and 2m wide and best observed in Ras El Aqaba area (Figs. 4 & 6). The lower surface of this lenticular mass truncates the bedding and lamination of the substrata and consists of a series of cut and fill structure. Its upper surface appears eroded. The conglomerate mass consists of sequential small fining-upward trough cross-sets interrupted by reactivation surfaces and thin intervals of horizontal stratifications consisting of fine-grained ferruginous sandstone and/or mudstone (Fig. 6). Each set begins with unconsolidated, poorly-sorted, rounded to subrounded clasts, 1-3 cm in diameter, of kaolinitic and chamositic mudstone, ferruginous and oolitic sandstone, ferruginous ooids and quartz. These are floating in ferruginous clayey matrix, and grading upward into foresets of finer granule conglomerates.

The composition, fining-upward tendancy and stratigraphic setting of this conglomerate type refer to the derivation of its components from nearby or continguous source and their deposition in storm-surge channel dissecting the crests and upper flanks of the migrated linear tidal sand/ooid bars and during waning of the storm activity. These conglomerates are correlatable with the storm channel lags formed at the mouth of a storm -

surge channel described by Brenner and Davies (1973). According to Reading (1978), the channel lags can be formed when storm activity coupled with increased tidal current velocities induced cross shoal currents to dissect the bar crests.

Intra-formational ironstone conglomerate

This ironstone type (up to 41-48 %Fe_2O_3) forms a set of lenticular bodies embedded in the basal mudstones of the fourth large-scale coarsening -upward cycle (Fig. 5). They represent a strange coarse deposits within fine-dominated (distal) facies in contrast to the coarse-grained sediment association (proximal) of the above described channel-fill type conglomerate. The conglomerate lenses are well represented in G. Um Barmil area (Fig. 5) where they range in thickness from 40 to 60 cm and may extend laterally for about 500 m. Their framework components are formed mainly of ferruginated mudstone and quartz setting in ferruginous clayey matrix. These components are poorly bedded, randomly oriented and are weakly imbricated. Some conglomerate lenses show local normal grading. Sole marks are not common. The framework components show varying degrees of breakages, ranging from nearly *in situ* brecciation and unabraded accumulations to finer matrix-supported comminuted and transported accumulations.

These conglomerates appear to be formed through syn-sedimentary erosion of subjacent mudstone during an intermittent storm-dominated events; reworking and redepositing of the produced clasts during the waning stage of the storm activities. The ironstone conglomerates of this type is similar in composition and internal fabrics to the storm-beds (tempestites) of the Clinton ironstone of the Appalachian Foreland Basin described by Cotter and Link (1993).

CONCLUSIONS AN SEDIMENTOLOGICAL MODEL

1. The Cretaceous ironstones of East Aswan are confined to the Timsah Formation which displays a shallow marine succession deposited during the Coniacian-Santonian southward advance of the Tethyan paleoshoreline. It consists mainly of four large-scale coarsening-upward cycles. Each of which is subdivided into smaller cycles of medium and small scales and represent a general shoaling regimes of a delimited time. Each cycle starts with general transgression and

deposition of thick basal mudstone-dominated unit; containing thin bands and lenses of ferruginous, kaolinitic and chamositic sandstone and siltstone (Fig. 7A). This basal unit is followed by a transitional unit of rhythmic alternation of mudstone, siltstone, sandstone and oolitic ironstone, comprising medium and small-scale coarsening-upward cycles (Fig. 7B). The rhythmic nature of this unit and the abundance of horizontal and ripple cross-laminations, symmetrical ripples and bioturbation as well as the textural maturity of the sands support deposition along lower and upper flanks of migrated sand/ooid bars during somehow stable period of very short and repeated sea level falls and rises (regression and transgression). The oolitic ironstone beds and the alternating and/or laterally equivalent sandstones of these middle rhythmic units are related to deposition during shoaling to the wave base, culminating in a ferruginous linear tidal ooid bars that deposited during waning stage of detrital input or sand bars that deposited in areas receiving much detrital input. The uppermost sheeted sandstone units terminating the large-scale coarsening-upward cycles (Fig. C) are suggested to be deposited during regressive phases, dominated by highly agitated storm-events. This is supported by the presence of storm lags and their lithology and sedimentary structures.

2. Based on the lithology, sedimentological aspects and composition of the Timsah ironstones, they are classified into three main groups which are further subdivided into 9 types.

C. Storm-generated reworked ironstone conglomerates.

9- Intra-formational ironstone conglomerate.

8- Channel-fill ironstone conglomerate

B. Oolitic ironstones

7- Oolitic sandy ironstones.

6- True oolitic ironstones.

5- Poorly "lean" oolitic ironstones.

A. Non-oolitic ironstones

4- Green laminated chamositic sandy ironstones.

2 & 3- Red and black sheeted sandy and silty ironstones.

1- Muddy banded and lenticular ironstones.

3. The muddy banded and lenticular ironstones are commonly present within the basal mudstone units of the large, medium and small-scale coarsening-upward cycles. Thin lamination of the muddy ironstones reflect deposition during shallow marine transgression and low clastic input. They are most probably formed just after or simultaneously with the deposition of the enclosing sediments (syngenetic).

   The red and black sheeted sandy and silty ironstones are usually associated with or just overlying the aforementioned muddy ironstones within the basal mudstone units of the second and third large-scale coarsening-upward cycles. They represent coarse-grained lithologies within the enclosing basal mudstones. They seem to be formed by the impact of currents and waves during periods of sand influxes interrupting the mudstone deposition. The abundance of Skolithos in these sheeted sandstone bands and lenses indicates deposition in the lowest-shale, wave-agitated upper shoreface and foreshore.

   The green laminated chamositic sandy ironstone is widespread in the basal part of the middle rhythmic unit of the large-scale coarsening-upward cycles. This ironstone type represents deposition during short and intermittent periods of sea regressions and transgression within the frame of the general seaward progradation of linear tidal sand/ooid bars. Petrographically, this ironstone type is composed mainly of chamositic-hematitic fine-grained sandstone.

4. The oolitic ironstones are subdivided into three types; poorly "lean" oolitic, true oolitic and oolitic sandy ironstones. This classification is based upon the proportion of the skeletal components relative to the enclosing clayey matrix and the proportion of the different skeletal components relative to each others. The stratigraphic position of the oolitic ironstones reflect their intimate genetic relation with short-lived transgressive-regressive events which are expressed by the small and medium-scale coarsening-upward cycles, developed during the long-lived progradation or coarsening-upward cycles.

The lithologic characteristics and sedimentary structures of the poorly "lean" oolitic ironstones and the underlying and equivalent green laminated sandstones and mudstones suggest deposition during the transgressive periods in a relatively calm condition along lower bar flanks or within

Fig. 7 Schematic diagrams showing the gradual progradation (migration) of the linear tidal bars on the shelf muds and accumulation of the oolitic ironstones (ironstone types 5,6 & 7).

A) Deposition of the basal mudstone unit (B) during a period of sea transgression ; general quite condition with occasional storm-surge currents.

B) Deposition of the middle rhythmic unit (M) during repeated transgressive-regressive periods.

C) Deposition of the upper storm-generated sandstone unit (U) in highly agitated (storm-dominated) condition during an ultimate stage of regression.

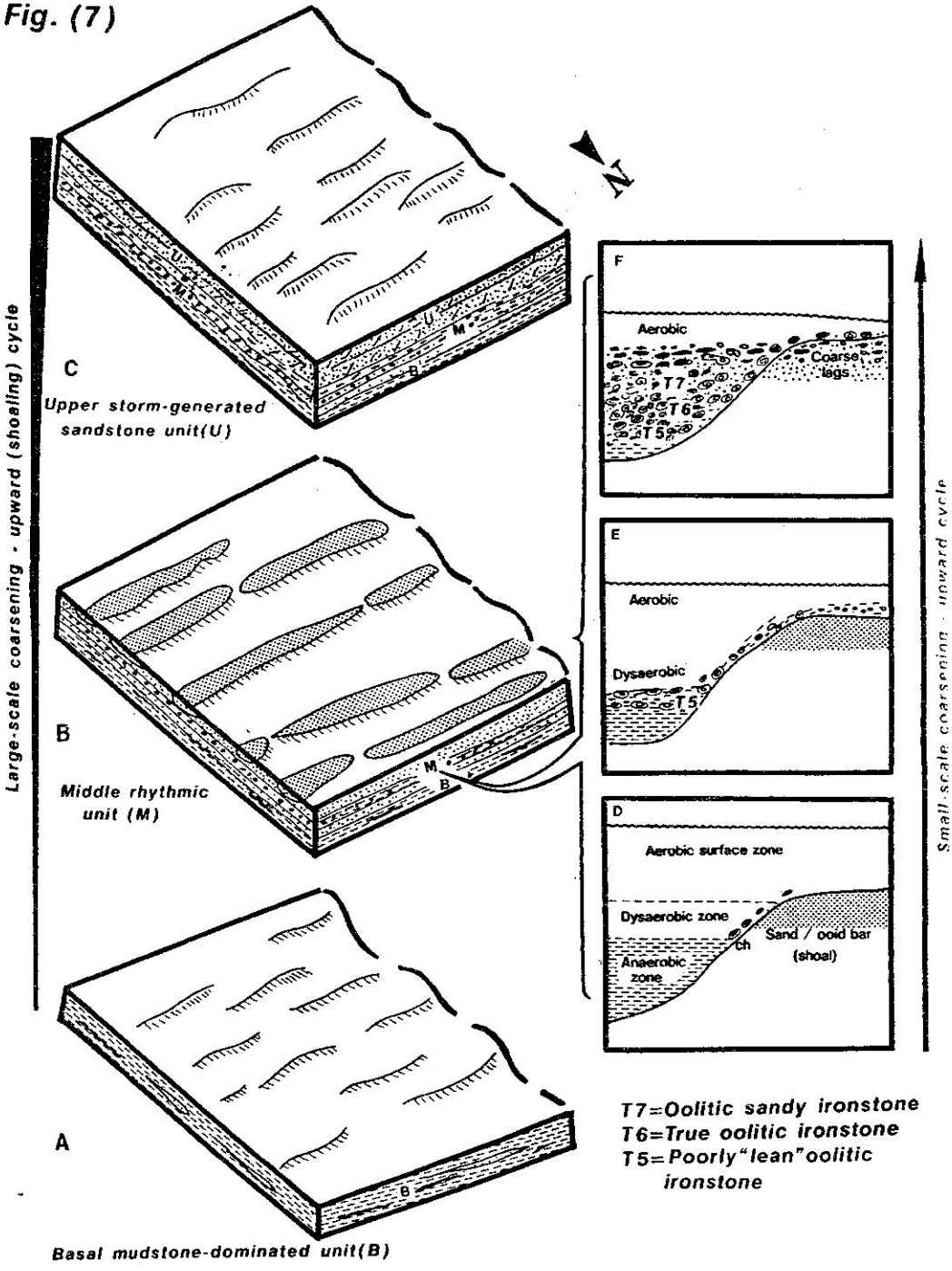
D-F) Formation of the oolitic ironstone types during the transgressive-regressive periods of the middle rhythmic unit (medium and small-scale cycles).

D) Short-lived period of sea transgression; deposition of the basal mudstone unit in the interbar areas (troughs) and formation of chamositic and chamositic-kaolinitic ooids along the bar flanks.

E) Initial stage of sea regression ; reworking and redeposition of the chamositic and chamositic-kaolinitic ooids within the mudstone forming poorly "lean" oolitic ironstone (type 5).

F) Ultimate stage of sea regression ; formation of kaolinitic, kaolinitic-hematitic and hematitic ooids and their redeposition forming true oolitic (type 6) and oolitic sandy (type 7) ironstones.

Fig. (7)


N
C
Upper storm-generated sandstone unit(U)
U
M
B
B
Middle rhythmic unit (M)
M
B
A
Basal mudstone-dominated unit(B)
B
Large-scale coarsening - upward (shoaling) cycle
F
Aerobic
Coarse lags
T7
T6
T5
E
Aerobic
Dysaerobic
T5
D
Aerobic surface zone
Dysaerobic zone
Anaerobic zone
ch
Sand / ooid bar (shoal)
Small-scale coarsening - upward cycle
T7=Oolitic sandy ironstone
T6=True oolitic ironstone
T5=Poorly "lean" oolitic ironstone

interbar areas (bar troughs), affected by an intermittent current activities. The stratigraphic setting of the true oolitic ironstones, their composition, textural maturity, internal sedimentary structures and lateral facies changes strongly emphasize the concentration of the ferruginous ooids in highly agitated conditions along bar flanks and bar crests during the regressive events which terminate the short-lived (small-scale) prograding regimes. The position of the chamositic ooids within the middle parts of the small-scale coarsening-upward cycles between the bioturbated and thinnly laminated basal mudstone below and increasing higher energy hematitic ooid above, may indicate their formation in the reducing dysaerobic transition zone (Cotter and Link, 1993) along the lower and upper flanks of the bars. On the other hand, the abundance of hematitic, kaolinitic-hematitic and kaolinitic ooids within the upper parts of the small-scale coarsening-upward cycles indicate their formation under somehow agitated oxidized conditions.

The progressive steps of ooid formation. within the small-scale coarsening-upward (prograding) cycles, can be summarized as follows:

a) Deposition of the suspended iron rich land-derived, fine detrital constituents (mainly kaolinite and iron oxyhydroxides and hematite crystallites) during periods of sea level rise or transgressive periods (Fig. 7D). This is accompanied with formation of chamositic ooids by mechanical accretion of green chamositic clay along the sediment-water interface.

b) Initial stage of regression (sea level fall), and winnowing, transportation and redeposition of the chamositic ooids together with green chamositic clays, forming poorly "lean" oolitic ironstone (Fig. 7E).

c) Formation of kaolinitic, kaolinitic-hematitic and hematitic ooids during an ultimate stage of regression or sea-level fall by mechanical accretion of kaolinite and iron-rich land-derived constituents in highly agitated condition and formation of the true oolitic and oolitic sandy ironstones (Types 6 & 7; Fig. 7F).

5. Two types of storm-generated ironstone conglomerates are observed: channel-fill ironstone conglomerates and intraformational ironstone conglomerates. The channel-fill ironstone conglomerates refer to deposition in storm channel dissecting the crests and upper

flanks of the migrated linear tidal sand/ooid bars. The intraformational ironstone conglomerates represent a strange coarse deposits within fine-dominated (distal) facies in contrast to the coarse-grained sediment association (proximal) of the channel-fill conglomerates. These conglomerates appear to be formed throught *in situ* brecciation of subjacent mudstone and redeposition of mudstone clasts during the waning stage of storm activities.

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الوضع الإستراتجرافى وبيئات الترسيب لصخور الكونياسى - السانتونى الحديديه بأسوان ، جنوب مصر

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تمثل الصخور الحديدية المتواجدة بمناطق شرق أسوان . المكونات الأساسية للتتابع الترسيبي الثاني و الثالث مكون التمساح الكونياسى – السانتونى العمر و ذو المنشأة البحرية الشاطئية .

مثل هذا المكون الترسيبات البحرية لبحر التيثيس أثناء تقدمه إلى مصر العليا إبان عصرى الكونياس – السانتونى و الذي يتكون من أربعة تتابعات ترسيبية رئيسية تتكون بدورها من وحده سفلية من الصخور الطينية تعلوها منظوم من الحجر الجيرى الرملي و الحديد البطروخى و الطين ثم تنتهي بوحدة علوية من أحجار رملية لوحيه نتجت من هبوط متكرر لسطح البحر صاحبة تقدم سلاسل من الحواجز الرملية آو البطروخية الشاطئية تنفصل عن بعضها و عن خط الشاطئ الأصلي ببحيرات شاطئيه .

هذا و قد تم تقسيم الصخور الحديدية المتواجدة في هذه التتابعات الرسوبية طبقا لتركيبها المعدني و أنسجتها الصخرية إلى ما يلي :

أولا : صخور حديدية غير بطروخية و تشمل على صخور حديدية طينيه و صخور حديدية رملية مكتفة داخل الوحدة الطينية السفلية للتتابعات مكون التمساح و التي تكونت في أماكن ما بين سلاسل الحواجز الرملية أو البطروخية الشاطئية و في بيئة ترسيب عميقة و هادئة نسبيا و نتيجة للترسيب المباشر من معلقات حديدية لا تيريتية المنشأ.

ثانيا : صخور حديدية بطروخيه متكونة من أجسام كروية (سريئات) من معادن الكاولين و الهيماتيت و سليكات الحديد المائية (شاهزايت) و تكون طبقات مختلفة الأسمال مكتفة داخل العصرات المنظومة الرملية المتوسطة لتتابعات مكون التمساح. و تدل تراكيبها الرسوبية الدولية و الثانوية على ترسيبها على جوانب و قمم الحواجز الرملية أو البطروخية الشاطئية بفعل أمواج بحرية عكره في بيئة ضحلة و عكرة.

ثالثا : رواسب حديدية كونجلو ميراتية تكونت بفعل موجات عاصفة فى ممرات بحرية تقطع الحواجز الرملية أو البطروخية أو تكونت في مكانها أثناء عمليات ما بعد الترسيب.